IO'S DIVERSE STYLES OF VOLCANIC ACTIVITY: RESULTS FROM GALILEO NIMS. R.M.C. Lopes[1], W.D. Smythe[1], L.W. Kamp[1], S. Doute'[2], R. Carlson[1], A.S. McEwen[3], P.E. Geissler[3], and the Galileo NIMS Team. [1]Jet Propulsion Laboratory/California Institute of Technology, Mail Stop 183-601, Pasadena, CA 91109, rlopes@lively.jpl.nasa.gov), [2]Laboratoire de Planetologie de Grenoble CNRS, Batiment D de Physique, B.P. 53, 38041 Grenoble Cedex 9, France, [3] Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721.

Introduction: The Near-Infrared Mapping Spectrometer on Galileo has observed Io since June 1996. In 1999 and 2000, the spacecraft made three close fly-bys to Io, revealing for the first time the detailed thermal structure of some of Io's hot spots. At the end of 2000, distant observations were again obtained, similar in spatial resolution to those obtained from 1996-1999. The combination of temporal data (from the distant observations) and high spatial resolution data (from the fly-bys) is used here to examine Io's diverse volcanic styles.

Results from Galileo NIMS and SSI, together with those from ground-based and Hubble Space Telescope observations (summarized in [1]) show 96 major volcanic regions on Io and 27 other locations where volcanic activity is suspected but not yet confirmed. The NIMS observations from the three fly-bys detected 15 hot spots that were not previously known. Out of these, 14 are located in an area around Prometheus that covers about 5% of Io's surface. Previous results from global observations [1] showed that the global distribution of hot spots on Io is uniform, with perhaps a slightly lower density towards the polar regions. The fly-by observations, taken at about 10 times the spatial resolution of the distant observations, revealed hot spots that are either too small or faint to be detected at lower spatial resolution. If the distribution of these faint hot spots is also uniform over Io's surface, we can expect that Io has some 300 active volcanic centers, most of which have not yet been detected. Future NIMS observations will target regions at higher latitudes to test whether the faint hot spots are uniformely distributed with latitude.

Some of the hot spots detected in the Prometheus region show significant variations in power output (at 4.7 microns) between the three fly-bys (I24, I25, and I27) which were only months apart. Observations of the Prometheus region in all three orbits were taken at similar spatial resolutions (20-25 km/NIMS pixel), but some hot spots were only detected in one orbit. This may imply rapid variations in eruption rate for the fainter hot spots which may have different plumbing systems than the persistent hot spots. Persistent hot spots such as Prometheus, Tupan, and Culann may be open systems where the magma supply rate balances the magma output rate.

During the fly-bys, NIMS observed a selection of hot spots at high spatial resolutions (typically 2-12 km/NIMS pixel). Among these were Prometheus, Amirani, Loki, Emakong, and Pele. Significant differences in the thermal structure and eruption styles of these hot spots were observed by NIMS.

Lava Flow Activity: Prometheus and Amirani. The temperature profile of the Prometheus flow is consistent with that of an insulated lava flow field. Hot material is erupting from a vent in the eastern end of the flow. The color temperature obtained from NIMS near the vent is 910±40 K. The flow may be moving through lava tubes, keeping the most of the surface at fairly constant, lower temperatures (240 to 460 K) than at the vent area. At the western end of the flow, close to where the plume is erupting, the increased temperatures (560±70 K) are consistent with lava being exposed as it emerges from tubes. This is consistent with the interpretation from SSI images [2]. The highest temperatures detected by NIMS only provide a lower limit for the eruption temperature, which is likely to be several hundred degrees hotter, impying either basaltic or ultramafic compositions.

The main Amirani flow appears similar to the Prometheus flow field at visible wavelengths, but thermal mapping by NIMS shows some significant differences. Amirani presents a more complex temperature distribution. Although thermal emission is seen along the whole north-south length of the main flow, it is concentrated in a few discrete areas, where temperatures reach up to 1000 K. This is consistent with breakouts of fresh lava along the flow and supports the interpretation of Keszthelyi et al. [2] that the Amirani flow field is similar to a compound flood basalt flow field on Earth, such as the Columbia River Basalts.

Calderas showing low temperatures: Loki, Emakong. Temperatures above about 400 K were not detected by NIMS at either of these hot spots, even at high spatial resolution. The thermal mapping of the Loki caldera was discussed in detail by Lopes-Gautier et al. [3] using data from NIMS and by Spencer et al. [4] using data Photopolarimeter Radiometer (PPR) during the fly-bys. Both instruments showed thermal emission from the dark materials on the caldera floor, but not from the light-colored materials that appear to form an island (or perhaps a raft) inside the caldera. A dark-colored crack or valley running through the island showed the highest color temperatures in the NIMS data (350 ± 55K). Median color temperatures for the dark floor material are 305 ± 44 K, however, NIMS did not image the southern part of the caldera floor, where data from PPR showed the highest floor temperatures (brightness temperatures from PPR data exceeded 370 K). Both PPR and NIMS data are consistent with the caldera being covered by flows of roughly uniform age, or a uniform crust on a lava lake [4].

Emakong is located in the center of the Bosphorus Regio, a region repeatedly observed by NIMS prior to the fly-bys, but from where no thermal emission was detected. Unless the NIMS observations consistently missed periods of intense activity, the implication of the lack of detection at low spatial resolution is that thermal emission has remained at a consistently low level. This implies that activity at Emakong is different from activity at Loki or at other Io hot spots. NIMS spectra from I24 and I27 detected the SO_2 absorption band at 4.1 microns within the same pixels as thermal emission (consistent with a color temperature of about 300 K). The Emakong caldera is the only location so far detected on Io that shows thermal emission and SO_2 within the same pixel (about 25 km^2 in area), implying that cold patches of SO_2 exist near volcanically active areas at a minimum temperature of 300 K. Williams et al. [5] proposed that the bright flows surrounding Emakong may be sulfur flows. If sulfur volcanism is taking place inside the caldera, the temperatures of the active sulfur flows would remain below about 400 K, consistent with what NIMS has observed. The relatively low temperature of sulfur volcanism compared to silicates would be more favorable to the co-existence of SO_2 and active volcanism within areas of the size of the NIMS pixels.

High temperatures at Pele. Prior to the fly-bys, temperatures consistent with ultramafic-type volcanism (>1500K) had only been obtained for Pillan [6]. One of the major questions about Io's volcanism is whether high-temperature lavas are present at many or only a few of the hot spots. Since lava cools quickly upon eruption, it is possible that eruption temperatures at any given hot spot are much higher than can be measured from orbit. This is particularly true in the case of low spatial resolution data that make it difficult to detect small areas having high temperatures. The NIMS night-time fly-by observation of Pele in I27 represented a good opportunity to attempt detection of high temperatures. (Observations taken during day-time are not well-suited for detecting the highest temperatures because of the difficulty of estimating albedo at short wavelengths, where the signal is dominated by reflected sunlight). We fit the NIMS spectra of Pele from I27 using a two-component fit and derived a median temperature for the hot component of T1=1760 ± 210K. This range implies that the Pele caldera has small areas where the lavas are at temperatures consistent with either basaltic or ultramafic compositions. Temperatures consistent with ultramafic volcanism have also been proposed for Tvashtar. SSI data of Tvashtar in I25 revealed temperatures high enough to cause 'bleeding" of pixels in the image [7].

These results show that the high temperatures previously detected at Pillan are not unique on Io. Although ultramafic-type temperatures have not yet been detected at most of Io's hot spots, it is feasible that such high temperatures are common. Higher resolution observations by NIMS during the fly-bys have increased detection of small areas at high temperatures. The NIMS fly-by observations have detected higher temperatures at Pele, Prometheus, and Amirani than could be determined from distant, lower resolution observations.

Further observations at high spatial resolution planned for 2001 and 2002 will help answer numerous questions posed by the results so far. Among future investigations will be regional observations of areas at high-latitudes and on the Jupiter-facing hemisphere to help determine the overall distribution of hot spots on the surface. The night-time observations planned by NIMS for future fly-bys will be particularly valuable to search for thermal emission from small areas at high temperatures that may indicate ultramafic-type volcanism.

References: [1] Lopes-Gautier, R. et al. (1999) *Icarus*, vol.140, no. 2, pp. 243-264. [2] Keszthelyi, L. et al. (2000), submitted to *J. Geophys. Res.* [3] Lopes-Gautier, R. et al. (2000), *Science*, 288, 1201-1204, 2000. [4] Spencer, J. et al. (2000) *Science*, vol. 288, pp. 1198-1201. [5] Williams, D. et al. (2000), submitted to *J. Geophys. Res.* [6] McEwen, A. et al. (1998) *Science* 281, 87-90. [7] McEwen, A. et al. (2000) *Science*, 1193-1198, 2000.